Chapter 5 Positions of the Sun and Moon

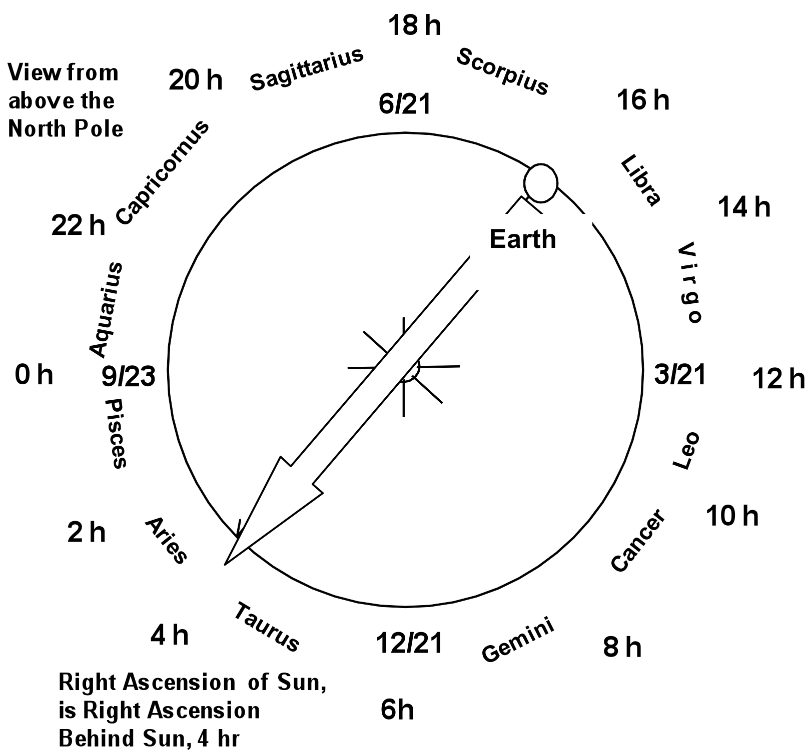
Objects in our Solar System appear to move over the course of weeks to months because they are so close. This motion caused ancient astronomers to use the name “planets”, which means “wanderers”. Comets also move among the stars, but they show tails and so were named differently. Asteroids, moons and planets past Saturn are too faint to see without telescopes, so they were unknown.

Since Solar System objects move, we do not memorize their positions the way that we do for stars. But we can understand how they move and specify their Right Ascensions and Declinations.

The Solar Motion

As we look from the Earth toward the Sun, it appears to be in front of the stars on the opposite side of our orbit. As the Earth orbits the Sun, this direction changes and the Sun appears to move in front of each of the constellations of the zodiac. The figure shows the view from above Earth’s North Pole.

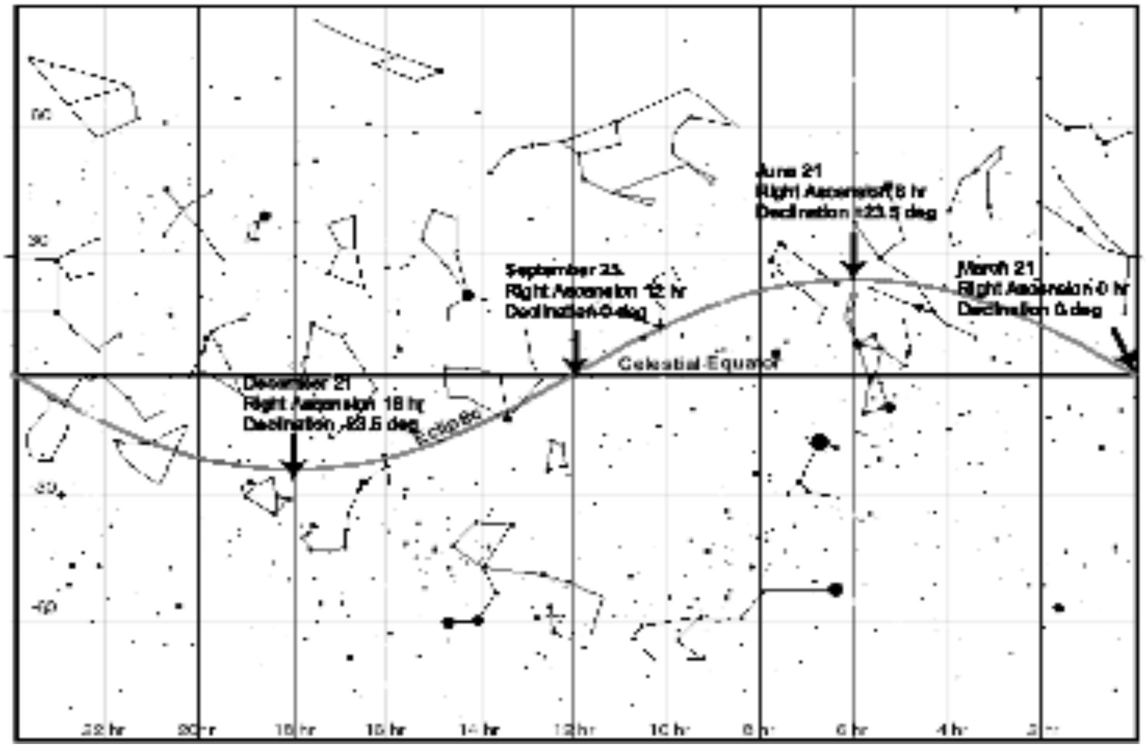
The Sun’s Right Ascension is the Right Ascension BEHIND the Sun as we look straight across our orbit. This direction is the same as the direction of the meridian at noon. Another way to look at it is that the Sun’s Right Ascension is always 12 hours different from the sidereal time at midnight. The Babylonians started to specify the Sun’s position using this concept**.**



Each year the Sun appears to move all the way through the constellations, at an average rate of a little less than 1 degree each day. This small motion is not very noticeable as you watch the sky. It is a much smaller effect than the rising and setting of the entire sky due to the Earth’s rotation.

The star map that follows shows the Sun’s path among the stars, the **ecliptic**. The Sun’s path is called the **ecliptic,** because eclipses of the Sun and/or Moon occur only when the Moon is nearly on the ecliptic. The rest of the planets and the asteroids are usually found near the ecliptic because the solar system is nearly a plane (flat).

On the star map, the ecliptic is a wavy line. It goes north and south of the celestial equator due to the tilt of the Earth’s axis. It is **defined** as the path of the Sun, so the Sun is ALWAYS ON the ecliptic, NEVER anywhere else. Once we find the Right Ascension of the Sun from the date, we find the point on the ecliptic with that Right Ascension, and then read off the declination.



One way to find the declination of the Sun is to remember the overall shape of the ecliptic curve it goes north to +23.5^o at 6hr Right Ascension, back to 0^o at 12hr Right Ascension, south to -23.5^o at 18hr Right Ascension,then back to 0^o and 0 hr. The Sun is at to 0^o and 0 hr Right Ascension on March 21, the traditional start of the year. The Sun is at positive declinations from March 21 through September 23, the traditional summer months in the northern hemisphere. It is at a southern declination during the rest of the year, the winter months.

Example: On Feb 21, the sidereal time is 10 hr at midnight. The noon sidereal time, the direction to the Sun, is 22 hr. So look at 22 hr, the Sun's Right Ascension, on the ecliptic, to find that the declination is -13^o .Thus the Sun's coordinates on Feb 21 are 22 hr and -13^o.

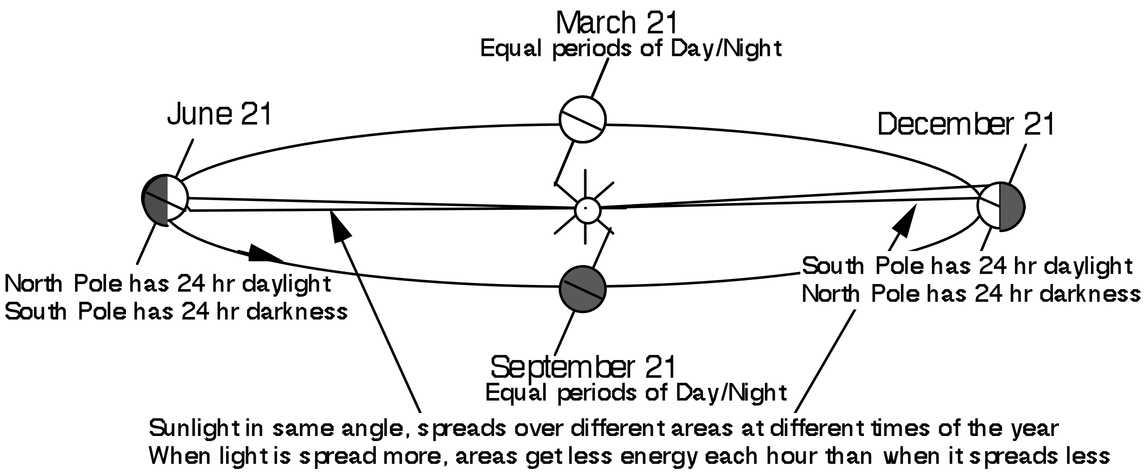
Check yourself: What is the Right Ascension and Declination of the Sun on Aug 21?

Seasons

As you have doubtless noticed, it is colder and there are fewer hours of daylight (out of each 24) during the winter. The main reason for this lies in the tilt of the Earth's axis.

The Earth's rotation axis is tilted about 23.5^o compared to the direction perpendicular to Earth's orbit. The axis keeps the same direction over the year. In summer, the pole in your hemisphere is tipped toward the Sun: in winter the other pole is. This causes the length of the daylight and the intensity of the light to change dramatically for latitudes far from the equator. The following figure shows how the tilted axis changes where the day/night line falls. On December 21, the entire north polar area is in shadow and the south pole area is in sunlight. On June 21, the situation is reversed.

Sunlight spreads over a larger area on the part of the Earth that is tilted away from the Sun and a smaller area in the hemispheres where the axis is pointed toward the Sun. So the hemisphere pointed away from the Sun gets fewer hours of daylight and the light it does get is spread out more and is less intense than average. This hemisphere gets colder and colder until the Earth's motion on its orbit changes the situation.

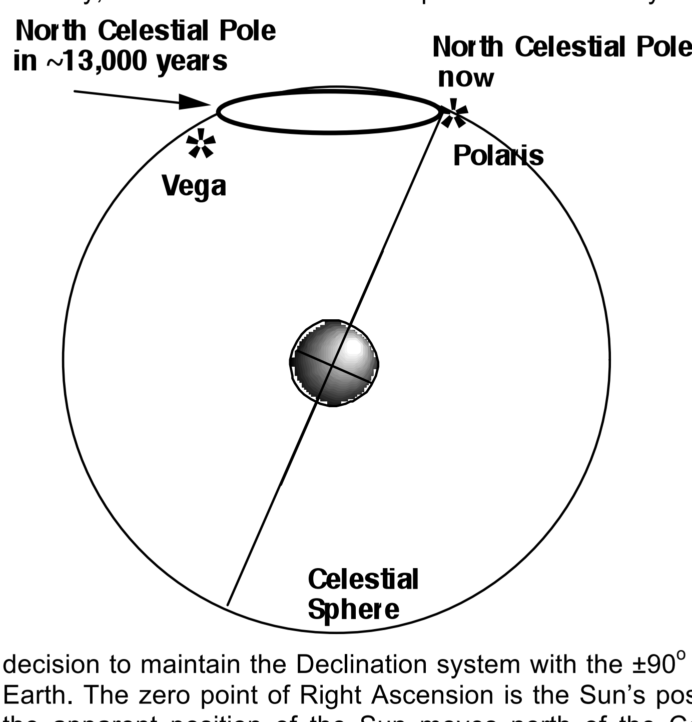


What about the effect of distance to the Sun? The earth's orbit is not exactly a circle. The distance varies by ±1.67%, with the closest point on the orbit occurring on Jan 6. This small distance change does not matter very much. It might seem that the southern hemisphere should have hotter summers and colder winters because the distance change accentuates its summer and winter. Actually, the land in the southern hemisphere is near the equator and there is a great deal of water. So the climate in the southern hemisphere is pretty mild.

Other planets, notably Mercury and Mars (and also Pluto), have orbits with substantial eccentricity. So their distances from the Sun vary considerably and the amount of light they get does too.

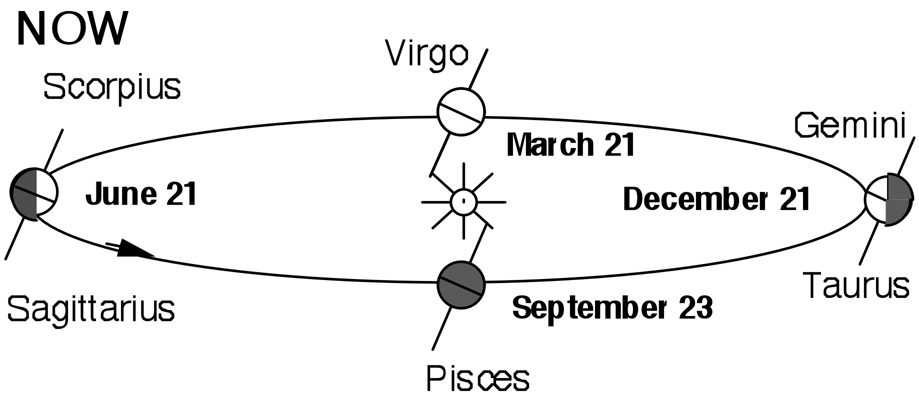
Precession

Actually, the direction that our axis points is NOT always the same. It rotates slowly with a period of ~25,800 years, The motion of the earth is shown in the figure. The direction of Earth's poles changes, but the stars do not. There is no "start date" or "end date" for the precession motion. It just continues.



The polar star maps in chapter 2 show the path of the poles in response to precession. When the Egyptian pyramids were built, the north star was the star Thuban, the brightest star in the constellation Draco (not very bright). The star Vega will be near the North Celestial Pole, the point above the Earth's North Pole, in about 12,900 years).

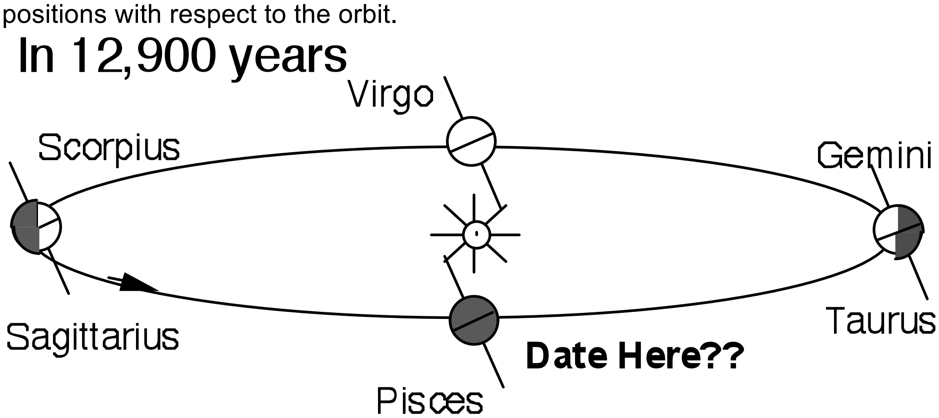
There has been a conscious decision to maintain the Declination system with the $\pm 90^o$ positions lined up with the poles of the Earth. The zero point of Right Ascension is the Sun's position on the Vernal Equinox (the when the apparent position of the Sun moves north of the Celestial Equator). As the Earth's axis changes direction, the coordinates of every object change. Generally there is no need to worry about the epoch since the change is so slow.



It may seem that the changes introduced by precession are too small to matter. But the change in declination is up to 47^{o} and the Right Ascension changes through the entire 24 hours. As the coordinates of an object change, whether it is always, sometimes or never visible from a location changes.

When accurate positions are published, they are given with the word "Epoch___", which specifies date for which the positions are computed. Computerized telescopes point to the current coordinates.

Precession changes the correspondence between the position of the Earth in its orbit and the season. In the preceding and the following pictures, the constellation names indicate the stars' positions with respect to the orbit.



What should the date be at the position labeled in ? There may be no one right answer, but the convention that we now are living by is that the date will be MARCH 21. Why? Because it is the Vernal Equinox, the date when the Sun goes north of the Celestial Equator.

A way to see this is to look at the Earth and its lighted day lit parts. Currently, summer in the Northern Hemisphere occurs when the Earth is on the left, where the North Pole gets 24 hours of daylight. In 12,900 years, the position of the Earth where the North Pole has 24 hours of daylight, will be on the right of the picture. We have chosen to keep the dates in the year aligned with the seasons. So summer in the north will remain in June. This is called the **Tropical Year**. There is no way to keep the dates and the seasons aligned and also keep the position of the earth in its orbit aligned with the dates.

The **Tropical Year**, has leap year days (Feb 29) at the proper interval to keep the seasons and the dates aligned. It has 365.242 days in a year. (To keep the same part of the orbit aligned with the same date we'd use the sidereal year, 365.2564 days.).

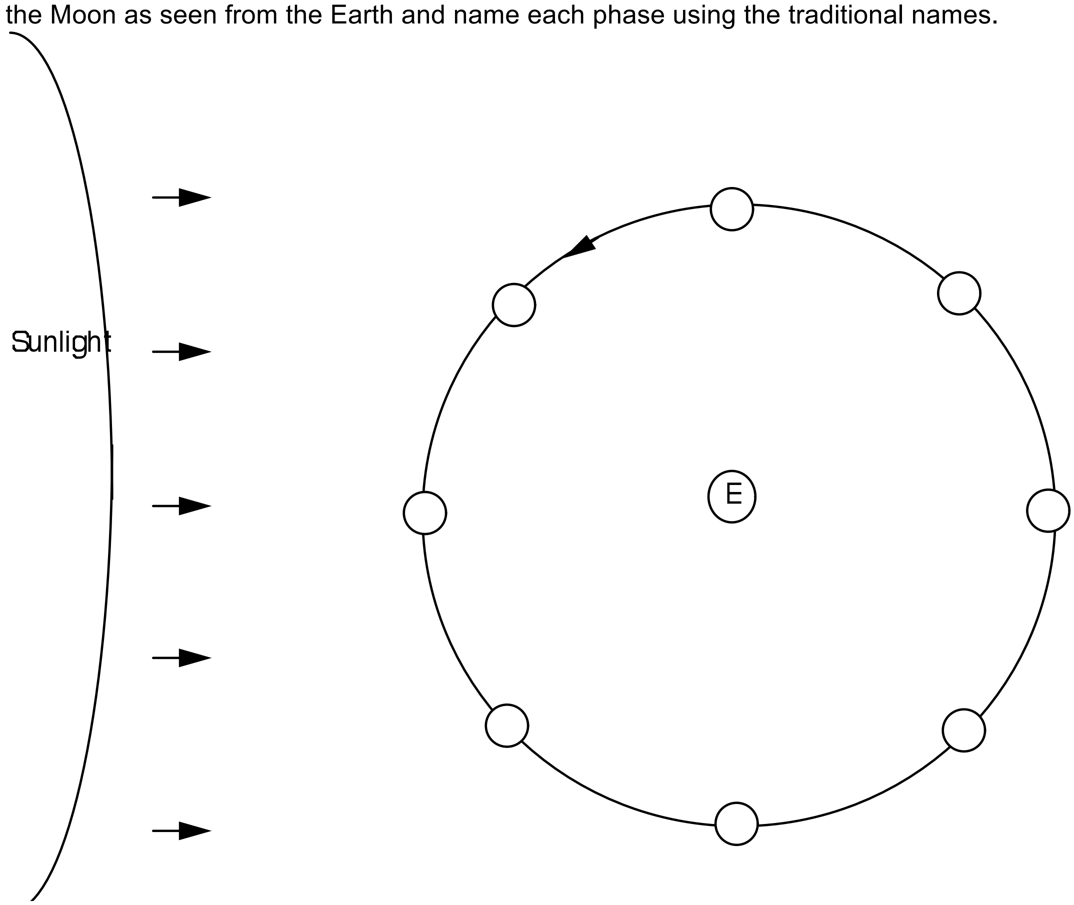
This combination of precession and the tropical year means that the Gemini and Taurus, which are seen near midnight in December will be seen near midnight in June in the future. You may

have noticed that correlation of constellation and date from your horoscope are different from the constellation behind the Sun on that same date. This is because the astrologers decided not to update the constellation correlation due to precession. The dates they use are from around the time of the Greeks (~2300 years ago). So what is your “real” sign?

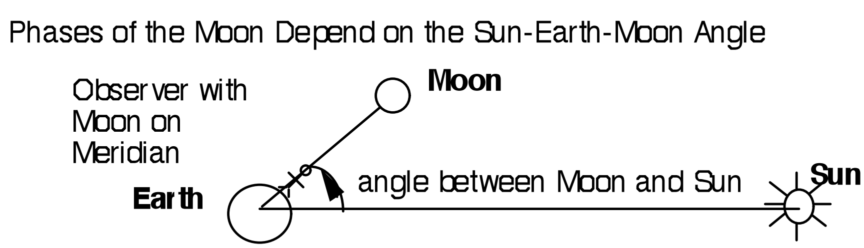
The Lunar Story The Moon orbits the Earth and moves around the Sun together with the Earth.

Earth revolves around the Sun (orbits) once per____________
Earth rotates on its axis once per ______________
Moon orbits the Earth once per ________________
Time between first quarter and full moon _________

Phases of the Moon depend on the angle to the Sun. As seen from above the North Pole, the half of the Moon toward the Sun is the bright part (that would be the left half in the figure below). But it doesn’t look the same as seen from the Earth. In the following picture draw the appearance of the Moon as seen from the Earth and name each phase using the traditional names.



Phases of the Moon depend only on the angle between Sun and Moon as seen from the Earth. Solar time works with the same angle shown.

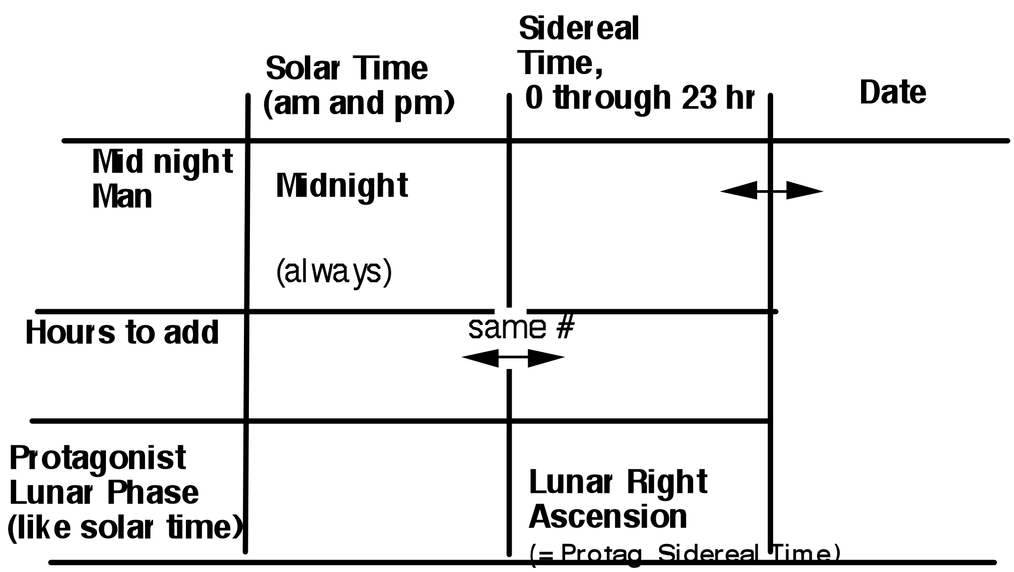


To cement your understanding, fill in the table.

Angle Observer and Sun as Seen from Earth	Solar time for the Observer	Moon Phase if it were on the Observer's Meridian
0 deg	Noon	New
45 deg		Waxing Crescent
	6PM	
135 deg	9PM	
		Full
225 deg	3AM	
270 deg		Third Quarter
	9AM	

If you want to know the time that the Moon is above the horizon, estimate that it rises 6 hours before the time from this table and sets 6 hours after that time. This approximates the situation for the equator.

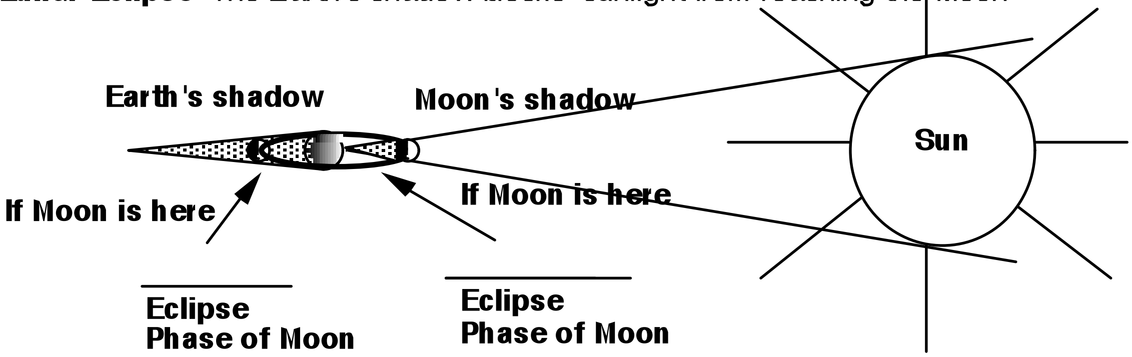
The Moon's **Right Ascension**, that is, the Right Ascension of the part of the sky behind the Moon, can be found from the day of the year and the phase of the Moon. The Moon's phase tells the Solar time when the Moon is on the meridian. Pretend the protagonist has that Solar Time (the one from the table above). Then use the date and the Solar Time, to find the Sidereal Time when the Moon, with its Right Ascension, is on the Meridian. **Sidereal Time = Moon's Right Ascension** when you complete the table**.**



Use the lunar phase to create a protagonist who has the Moon on the observer's meridian. Then use the table to find the protagonist's sidereal time. This is the same value as the Moon's Right Ascension.

Eclipses: Definitions and Geometry

Solar Eclipse The Moon blocks the Sun
Lunar Eclipse The Earth's shadow blocks sunlight from reaching the Moon



The Moon and Sun appear to be the same size in the Sky. How can this be?
Are they really the same size in kilometers? So how can they look the same?
The distances to the Sun and the Moon just right to make the two appear nearly the sam size. We are the only planet in our Solar System where a Solar Eclipse occurs. Other planets DO have lunar eclipses.

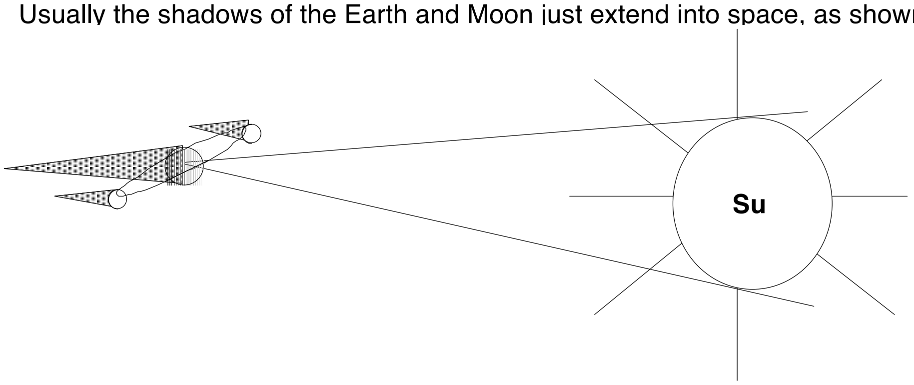
The Moon's shadow ends near the surface of the Earth. If the Moon is too far from the Earth, the shadow does not touch and the Sun does not appear totally covered. This is called an **Annular Eclipse**. Even when the Moon's shadow touches the Earth, the shadowed part of the Earth is small ,so a Total Solar Eclipse lasts 7 minutes or less.

In contrast, the Earth's shadow, is substantially larger than the Moon where the Moon passes through it. So total Lunar Eclipses last for more than an hour.

How often do Eclipses

The inclination of the Moon's orbit, approximately 5 degrees, keeps the shadows of both Earth and Moon from causing eclipses unless Earth, Moon and Sun are nearly in a straight line.

Usually the shadows of the Earth and Moon just extend into space, as shown,

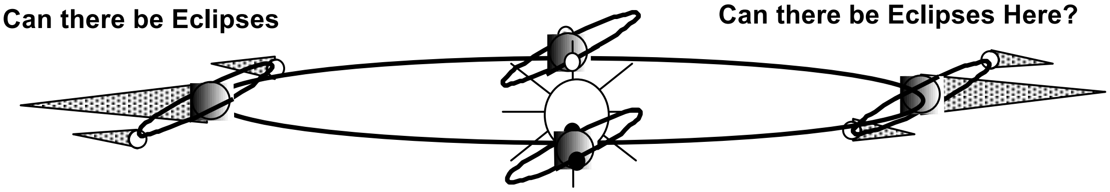


For an eclipse to occur, the intersection of the planes of the Earth's orbit and the Moon's orbit, **line of nodes,** must be nearly along the direction toward and away from the Sun. (The nodes are the points where the Moon's orbit and the Earth's orbit cross and the line of nodes joins the two intersections)

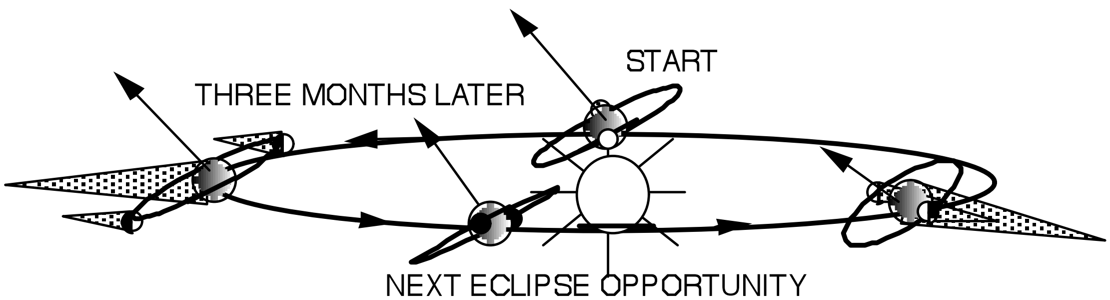
When the nodes are properly aligned, a Lunar and a Solar eclipse always occur, one at new moon, the other at full moon, about two weeks apart. Sometimes the alignment of the line of nodes is just right and three eclipses occur over one lunar month.

Once the two or three eclipses have occurred, this “eclipse season” is over. There cannot be any more eclipses until the line of nodes again points toward the Sun, nearly six months later.

If the Moon’s orbit did not change, the situation would be like the drawing immediately below.



But, the tilt of the Moon’s orbit changes both direction and angle. The direction of the tilt makes a complete rotation every 18.6 years due to the gravity from the Sun and the other planets. As the direction changes, the line of nodes regresses, i.e. it goes retrograde and the alignment of the nodes for another eclipse season occurs less that 6 months after the previous one. The diagram below depicts the how the direction changes.



EXAGGERATED EFFECT OF ROTATION OF THE MOON'S ORBIT

The tilt of the orbit varies from about 9 minutes (0.15 degrees) on a 173 day cycle.

Orientation Practice Problems Set IV

1) At what time is the first quarter Moon on the meridian?
2) If you can see a crescent moon and it is 5 AM, is it a waxing or a waning moon?
3) You want to fish in the darkness (so the fish won’t see your boat, but you want to launch the boat in moonlight (so that you can see what you are doing), but after sunset. You will fish from 3AM until after dawn and you do not want to sit in the boat starting from sunset.
4) If it is full moon on Oct. 15, when is the new moon?
5) If there is a third quarter moon on April 1, when will waning crescent be?
6) If it is March 21, what is the Right Ascension of the third quarter moon?
7) If it is Oct. 7, what is the Right Ascension of the waxing gibbous moon?
8) If you see the waning crescent moon at 15 hr Right Ascension, what is the date?
9) When the waxing crescent moon is in Taurus, at 4 hr, what is the date?
10) What is the Right Ascension of the third quarter moon on May 7?
11) If there is a lunar eclipse on March 12, when can there be a solar eclipse?
12) What is the Right Ascension and declination of the Sun on Jan21?

Answers
Solar position on Aug 22 the Right Ascension is about 10 hr and the declination is about $+12^{o}$
Answers Set IV
1) 6 PM 2) Waning 3) You want the moon to set at 3 AM, so it must be Waxing Gibbous. 4) Oct. 29 5) April 5 6) 18 hr 7) 22 hr 8) Treat it as though the protagonist were at 9 AM, so midnight is 9 hr earlier or at 6 hr, which makes it Dec. 21. 9) April 7 10) 21 hr 11) Either 2 weeks before, two weeks after, or 5 and one half lunar months later (or earlier) 12) 20 hr and -20^{O}

Solar Eclipses 2005-2030 Eclipse Predictions by Fred Espenak,NASA/GSFC

Date	Eclipse Type	Saros	Eclipse Magnitude	Central Duration	Geographic Region of Eclipse Visibility
2005 Apr 08	Hybrid	129	1.007	00m42s	N. Zealand, N. & S. America [Hybrid: s Pacific, Panama, Colombia, Venezuela]
2005 Oct 03	Annular	134	0.958	04m32s	Europe, Africa, s Asia [Annular: Portugal, Spain, Libya, Sudan, Kenya]
2006 Mar 29	Total	139	1.052	04m07s	Africa, Europe, w Asia [Total: c Africa, Turkey, Russia]
2006 Sep 22	Annular	144	0.935	07m09s	S. America, w Africa, Antarctica [Annular: Guyana, Suriname, F. Guiana, s Atlantic]
2007 Mar 19	Partial	149	0.874	-	Asia, Alaska
2007 Sep 11	Partial	154	0.749	-	S. America, Antarctica
2008 Feb 07	Annular	121	0.965	02m12s	Antarctica, e Australia, N. Zealand [Annular: Antarctica]
2008 Aug 01	Total	126	1.039	02m27s	ne N. America, Europe, Asia [Total: n Canada, Greenland, Siberia, Mongolia, China]
2009 Jan 26	Annular	131	0.928	07m54s	s Africa, Antarctica, se Asia, Australia [Annular: s Indian, Sumatra, Borneo]
2009 Jul 22	Total	136	1.080	06m39s	e Asia, Pacific Ocean, Hawaii [Total: India, Nepal, China, c Pacific]
2010 Jan 15	Annular	141	0.919	11m08s	Africa, Asia [Annular: c Africa, India, Malymar, China]
2010 Jul 11	Total	146	1.058	05m20s	s S. America [Total: s Pacific, Easter Is., Chile, Argentina]
2011 Jan 04	Partial	151	0.857	-	Europe, Africa, c Asia
2011 Jun 01	Partial	118	0.601	-	e Asia, n N. America, Iceland
2011 Jul 01	Partial	156	0.097	-	s Indian Ocean
2011 Nov 25	Partial	123	0.905	-	s Africa, Antarctica, Tasmania, N.Z.
2012 May 20	Annular	128	0.944	05m46s	Asia, Pacific, N. America [Annular: China, Japan, Pacific, w U.S.]
2012 Nov 13	Total	133	1.050	04m02s	Australia, N.Z., s Pacific, s S. America [Total: n Australia, s Pacific]
2013 May 10	Annular	138	0.954	06m03s	Australia, N.Z., c Pacific [Annular: n Australia, Solomon Is., c Pacific]
2013 Nov 03	Hybrid	143	1.016	01m40s	e Americas, s Europe, Africa [Hybid: Atlantic, c Africa]
2014 Apr 29	Annular	148	0.984	-	s Indian, Australia, Antarctica [Annular: Antarctica]
2014 Oct 23	Partial	153	0.811	-	n Pacific, N. America
2015 Mar 20	Total	120	1.045	02m47s	Iceland, Europe, n Africa, n Asia [Total: n Atlantic, Faeroe Is, Svalbard]
2015 Sep 13	Partial	125	0.787	-	s Africa, s Indian, Antarctica
2016 Mar 09	Total	130	1.045	04m09s	e Asia, Australia, Pacific [Total: Sumatra, Borneo, Sulawesi, Pacific]
2016 Sep 01	Annular	135	0.974	03m06s	Africa, Indian Ocean [Annular: Atlantic, c Africa, Madagascar, Indian]
2017 Feb 26	Annular	140	0.992	00m44s	s S. America, Atlantic, Africa, Antarctica [Annular: Pacific, Chile, Argentina, Atlantic, Africa]
2017 Aug 21	Total	145	1.031	02m40s	N. America, n S. America [Total: n Pacific, U.S., s Atlantic]
2018 Feb 15	Partial	150	0.599	-	Antarctica, s S. America
2018 Jul 13	Partial	117	0.337	-	s Australia
2018 Aug 11	Partial	155	0.736	-	n Europe, ne Asia

Date	Eclipse Type	Saros	Eclipse Magnitude	Central Duration	Geographic Region of Eclipse Visibility
2019 Jan 06	Partial	122	0.715	-	ne Asia, n Pacific
2019 Jul 02	Total	127	1.046	04m33s	s Pacific, S. America [Total: s Pacific, Chile, Argentina]
2019 Dec 26	Annular	132	0.970	03m39s	Asia, Australia [Annular: Saudi Arabia, India, Sumatra, Borneo]
2020 Jun 21	Annular	137	0.994	00m38s	Africa, se Europe, Asia [Annular: c Africa, s Asia, China, Pacific]
2020 Dec 14	Total	142	1.025	02m10s	Pacific, s S. America, Antarctica [Total: s Pacific, Chile, Argentina, s Atlantic]
2021 Jun 10	Annular	147	0.943	03m51s	n N. America, Europe, Asia [Annular: n Canada, Greenland, Russia]
2021 Dec 04	Total	152	1.037	01m54s	Antarctica, S. Africa, s Atlantic [Total: Antarctica]
2022 Apr 30	Partial	119	0.639	-	se Pacific, s S. America
2022 Oct 25	Partial	124	0.861	-	Europe, ne Africa, Mid East, w Asia
2023 Apr 20	Hybrid	129	1.013	01m16s	se Asia, E. Indies, Australia, Philippines. N.Z. [Hybrid: Indonesia, Australia, Papua New Guinea]
2023 Oct 14	Annular	134	0.952	05m17s	N. America, C. America, S. America [Annular: w US, C. America, Columbia, Brazil]
2024 Apr 08	Total	139	1.057	04m28s	N. America, C. America [Total: Mexico, c US, e Canada]
2024 Oct 02	Annular	144	0.933	07m25s	Pacific, s S. America [Annular: s Chile, s Argentina]
2025 Mar 29	Partial	149	0.936	-	nw Africa, Europe, n Russia
2025 Sep 21	Partial	154	0.853	-	s Pacific, N.Z., Antarctica
2026 Feb 17	Annular	121	0.963	02m20s	s Argentina & Chile, s Africa, Antarctica [Annular: Antarctica]
2026 Aug 12	Total	126	1.039	02m18s	n N. America, w Africa, Europe [Total: Arctic, Greenland, Iceland, Spain]
2027 Feb 06	Annular	131	0.928	07m51s	S. America, Antarctica, w & s Africa [Annular: Chile, Argentina, Atlantic]
2027 Aug 02	Total	136	1.079	06m23s	Africa, Europe, Mid East, w & s Asia [Total:Morocco, Spain, Algeria, Libya, Egypt, Saudi Arabia, Yemen, Somalia]
2028 Jan 26	Annular	141	0.921	10m27s	e N. America, C. & S. America, w Europe, nw Africa [Annular: Ecuador, Peru, Brazil, Suriname, Spain, Portugal]
2028 Jul 22	Total	146	1.056	05m10s	SE Asia, E. Indies, Australia, N.Z. [Total: Australia, N. Z.]
2029 Jan 14	Partial	151	0.871	-	N. America, C. America
2029 Jun 12	Partial	118	0.458	-	Arctic, Scandanavia, Alaska, n Asia, n Canada
2029 Jul 11	Partial	156	0.230	-	s Chile, s Argentina
2029 Dec 05	Partial	123	0.891	-	s Argentina, s Chile, Antarctica
2030 Jun 01	Annular	128	0.944	05m21s	Europe, n Africa, Mid East, Asia, Arctic, Alaska [Annular: Algeria, Tunesia, Greece, Turkey, Russia, n. China, Japan]
2030 Nov 25	Total	133	1.047	03m44s	s Africa, s Indian Ocean., E. Indies, Australia, Antarctica [Total: Botswana, S. Africa, Australia]

[1] **Greatest Eclipse** is the time at minimum distance between the Moon's shadow axis and Earth's center.

[2] **Hybrid** eclipses are also known as **annular/total** eclipses. Such an eclipse is both total and annular along different sections of its umbral path.

[3] **Eclipse magnitude** is the fraction of the Sun's diameter obscured by the Moon. For annular eclipses, the eclipse magnitude is less than 1; for total eclipses, greater than or equal to 1. The value listed is Moon's apparent diameter divided by the Sun's.

[4] **Central Duration** is the duration of a total or annular eclipse at **Greatest Eclipse** (see 1).

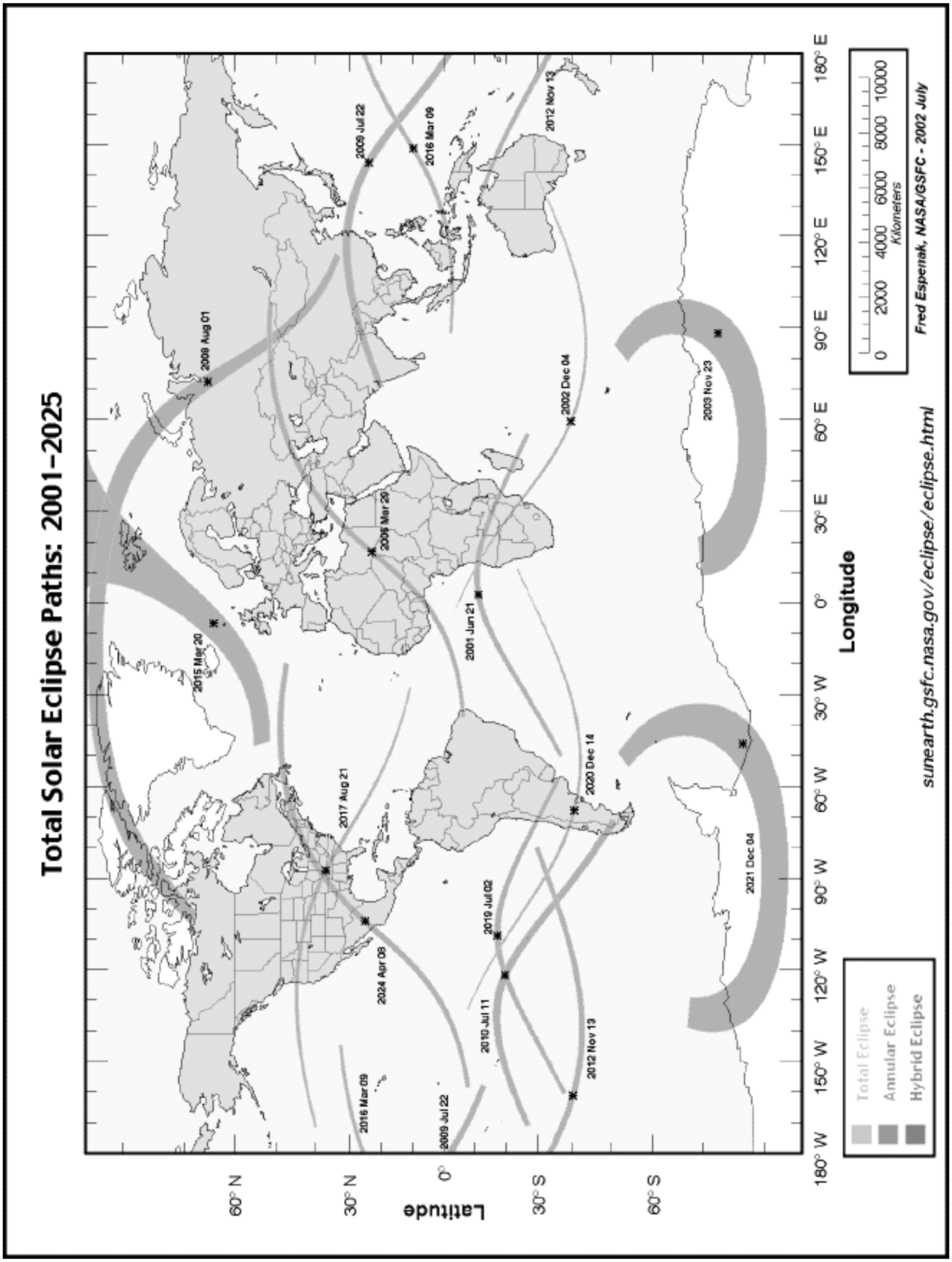
[5] **Geographic Region of Eclipse Visibility** is the portion of Earth's surface where a partial eclipse can be seen. The central path of a total or annular eclipse is described inside the brackets [].

This information and more can be found at http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Lunar Eclipses Eclipse Predictions by Fred Espenak,NASA/GSFC

Date	Type	Saros	Fractional coverage	Eclipse Duration (Totality Duration)	Locations where visible
2005 Apr 24	Penumbral	141	-0.139	-	e Asia, Aus., Pacific, Americas
2005 Oct 17	Partial	146	0.068	00h58m	Asia, Aus., Pacific, North America
2006 Mar 14	Penumbral	113	-0.055	-	Americas, Europe, Africa, Asia
2006 Sep 07	Partial	118	0.189	01h33m	Europe, Africa, Asia, Aus.
2007 Mar 03	Total	123	1.238	03h42m (**01h14m**)	Americas, Europe, Africa, Asia
2007 Aug 28	Total	128	1.481	03h33m **(01h31m)**	e Asia, Aus., Pacific, Americas
2008 Feb 21	Total	133	1.111	03h26m **(00h51m)**	c Pacific, Americas, Europe, Africa
2008 Aug 16	Partial	138	0.813	03h09m	S. America, Europe, Africa, Asia, Aus.
2009 Feb 09	Penumbral	143	-0.083	-	e Europe, Asia, Aus., Pacific, w N.A.
2009 Jul 07	Penumbral	110	-0.909	-	Aus., Pacific, Americas
2009Aug 06	Penumbral	148	-0.661	-	Americas, Europe, Africa, w Asia
2009 Dec 31	Partial	115	0.082	01h02m	Europe, Africa, Asia, Aus.
2010 Jun 26	Partial	120	0.542	02h44m	e Asia, Aus., Pacific, w Americas
2010 Dec 21	Total	125	1.262	03h29m **(01h13m)**	e Asia, Aus., Pacific, Americas, Europe
2011 Jun 15	Total	130	1.705	03h40m (**01h41m)**	S.America, Europe, Africa, Asia, Aus.
2011 Dec 10	Total	135	1.110	03h33m **(00h52m)**	Europe, e Africa, Asia, Aus., Pacific, N.A.
2012 Jun 04	Partial	140	0.376	02h08m	Asia, Aus., Pacific, Americas
2012 Nov 28	Penumbral	145	-0.184	-	Europe, e Africa, Asia, Aus., Pacific, N.A.
2013 Apr 25	Partial	112	0.020	00h32m	Europe, Africa, Asia, Aus.
2013 May 25	Penumbral	150	-0.928	-	Americas, Africa
2013 Oct 18	Penumbral	117	-0.266	-	Americas, Europe, Africa, Asia
2014 Apr 15	Total	122	1.296	03h35m **(01h19m)**	Aus., Pacific, Americas
2014 Oct 08	Total	127	1.172	03h20m **(01h00m)**	Asia, Aus., Pacific, Americas
2015 Apr 04	Total	132	1.006	03h30m **(00h12m)**	Asia, Aus., Pacific, Americas
2015 Sep 28	Total	137	1.282	03h21m **(01h13m)**	e Pacific, Americas, Europe, Africa, w Asia
2016 Mar 23	Penumbral	142	-0.307	-	Asia, Aus., Pacific, w Americas
2016 Aug 18	Penumbral	109	-0.992	-	Aus., Pacific, Americas
2016nSep 16	Penumbral	147	-0.058	-	Europe, Africa, Asia, Aus., w Pacific
2017 Feb 11	Penumbral	114	-0.031	-	Americas, Europe, Africa, Asia
2017 Aug 07	Partial	119	0.252	01h57m	Europe, Africa, Asia, Aus.
2018 Jan 31	Total	124	1.321	03h23m **(01h17m)**	Asia, Aus., Pacific, w N.America
2018 Jul 27	Total	129	1.614	03h55m (**01h44m)**	S.America, Europe, Africa, Asia, Aus.
2019 Jan 21	Total	134	1.201	03h17m **(01h03m)**	c Pacific, Americas, Europe, Africa

Date	Type	Saros	Fractional coverage	Eclipse Duration (Totality Duration)	Locations where visible
2019 Jul 16	Partial	139	0.657	02h59m	S.America, Europe, Africa, Asia, Aus.
2020 Jan 10	Penumbral	144	-0.111	-	Europe, Africa, Asia, Aus.
2020 Jun 05	Penumbral	111	-0.399	-	Europe, Africa, Asia, Aus.
2020 Jul 05	Penumbral	149	-0.639	-	Americas, sw Europe, Africa
2020 Nov 30	Penumbral	116	-0.258	-	Asia, Aus., Pacific, Americas
2021 May 26	Total	121	1.016	03h08m **(00h19m)**	e Asia, Australia, Pacific, Americas
2021 Nov 19	Partial	126	0.978	03h29m	Americas, n Europe, e Asia, Australia, Pacific
2022 May 16	Total	131	1.419	03h28m **(01h26m)**	Americas, Europe, Africa
2022 Nov 08	Total	136	1.364	03h40m **(01h26m)**	Asia, Australia, Pacific, Americas
2023 May 05	Penumbral	141	-0.041	-	Africa, Asia, Australia
2023 Oct 28	Partial	146	0.128	01h19m	e Americas, Europe, Africa, Asia, Australia
2024 Mar 25	Penumbral	113	-0.127	-	Americas
2024 Sep 18	Partial	118	0.090	01h05m	Americas, Europe, Africa
2025 Mar 14	Total	123	1.183	03h39m **(01h06m)**	Pacific, Americas, w Europe, w Africa
2025 Sep 07	Total	128	1.367	03h30m **(01h23m)**	Europe, Africa, Asia, Australia
2026 Mar 03	Total	133	1.155	03h28m **(00h59m)**	e Asia, Australia, Pacific, Americas
2026 Aug 28	Partial	138	0.935	03h19m	e Pacific, Americas, Europe, Africa
2027 Feb 20	Penumbral	143	-0.052	-	Americas, Europe, Africa, Asia
2027 Jul 18	Penumbral	110	-1.063	-	e Africa, Asia, Australia, Pacific
2027 Aug 17	Penumbral	148	-0.521	-	Pacific, Americas
2028 Jan 12	Partial	115	0.072	00h59m	Americas, Europe, Africa
2028 Jul 06	Partial	120	0.394	02h23m	Europe, Africa, Asia, Australia
2028 Dec 31	Total	125	1.252	03h30m **(01h12m)**	Europe, Africa, Asia, Australia, Pacific
2029 Jun 26	Total	130	1.849	03h40m **(01h43m)**	Americas, Europe, Africa, Mid East
2029 Dec 20	Total	135	1.121	03h34m **(00h55m)**	Americas, Europe, Africa, Asia
2030 Jun 15	Partial	140	0.508	02h25m	Europe, Africa, Asia, Australia
2030 Dec 09	Penumbral	145	-0.159	-	Americas, Europe, Africa, Asia



Total Solar Eclipse Paths: 2001–2025
Latitude
Longitude
60° N
30° N
0°
30° S
60° S
180° W
150° W
120° W
90° W
60° W
30° W
0°
30° E
60° E
90° E
120° E
150° E
180° E
2001 Jun 21
2002 Dec 04
2003 Nov 23
2006 Mar 29
2008 Aug 01
2009 Jul 22
2010 Jul 11
2012 Nov 13
2015 Mar 20
2016 Mar 09
2017 Aug 21
2019 Jul 02
2020 Dec 14
2021 Dec 04
2024 Apr 08
Total Eclipse
Annular Eclipse
Hybrid Eclipse
0 2000 4000 6000 8000 10000
Kilometers
Fred Espenak, NASA/GSFC - 2002 July
sunearth.gsfc.nasa.gov/eclipse/eclipse.html